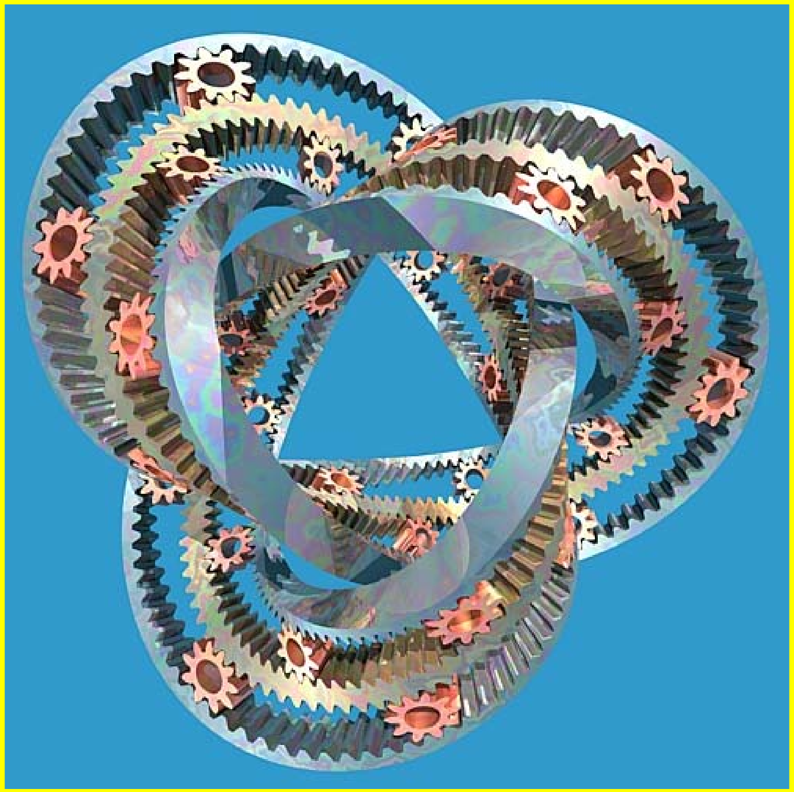
Rapid Prototyping

Definition : a class of technologies that can automatically construct physical models from Computer-Aided Design (CAD) data. (William Palm (May 1998), revised 30 July 2002, Penn State University)



Mobious Gears, Raytraced

Mobious Gears Rapid Prototyped (SL)

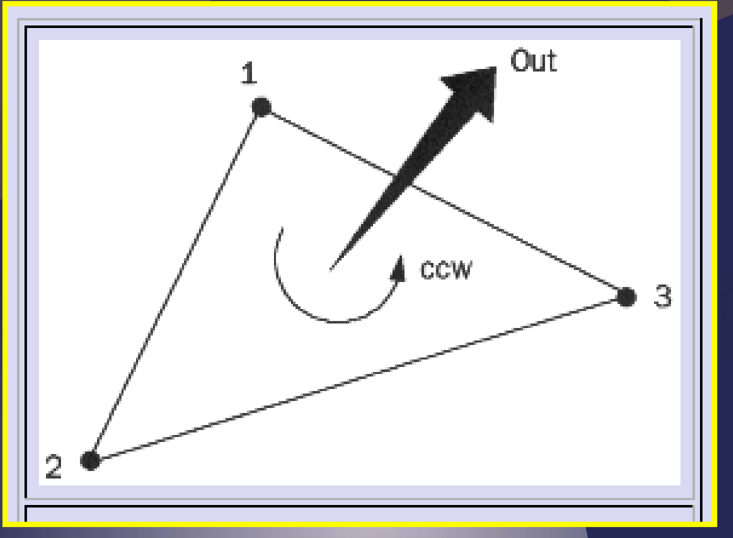
The Basic Process

- Create a CAD model of the design
- Convert the CAD model to STL format
- Slice the STL file into thin cross-sectional layers
- Construct the model one layer atop another
- Clean and finish the model

What is a STL File?

- STL Stands for Stereolithographic File
- The purpose of .STL file is to make Complex 3D data from a CAD model (e.g SolidWorks) easy to be read by a Rapid Prototype Machine.
- Files can be Binary or ASCII in format.
- The file contains triangular planar faces (facets)

What is a Facet ?



A facet is a triangle which represents a part of the surface of a 3D object.

The orientation of a facet is determined by the unit normal and the order in which the vertices are listed.

A conventional mirror ball uses square facets to represent a sphere.

STL File Structure - ASCII

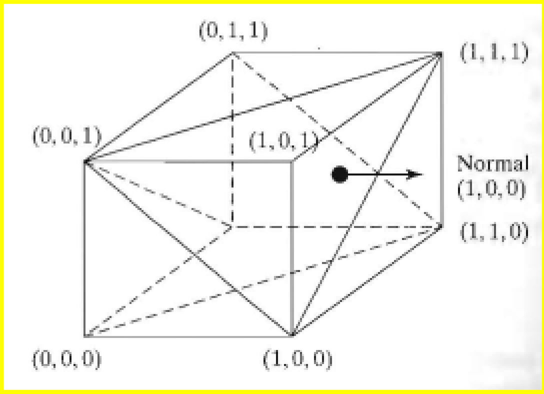
- Bold face indicates a keyword; these must appear in lower case.
- Note that there is a space in “facet normal” and in “outer loop,” while there is no space in any of the keywords beginning with “end.”
- Indentation must be with spaces; tabs are not allowed.
- The notation, “{…}$^+$,” means that the contents of the brace brackets can be repeated one or more times.
- Symbols in italics are variables which are to be replaced with user-specified values.
- The numerical data in the **facet normal** and **vertex** lines are single precision floats, for example, 1.23456E+789.
- A **facet normal** coordinate may have a leading minus sign; a **vertex** coordinate may not.

solid *name*

$$\left\{\begin{array}{l}
\textbf{facet normal}\ n_i\ n_j\ n_k \\
\quad \textbf{outer loop} \\
\qquad \textbf{vertex}\ v1_x\ v1_y\ v1_z \\
\qquad \textbf{vertex}\ v2_x\ v2_y\ v2_z \\
\qquad \textbf{vertex}\ v3_x\ v3_y\ v3_z \\
\quad \textbf{endloop} \\
\textbf{endfacet}
\end{array}\right\}^+$$

endsolid *name*

Example of a ASCII .STL file

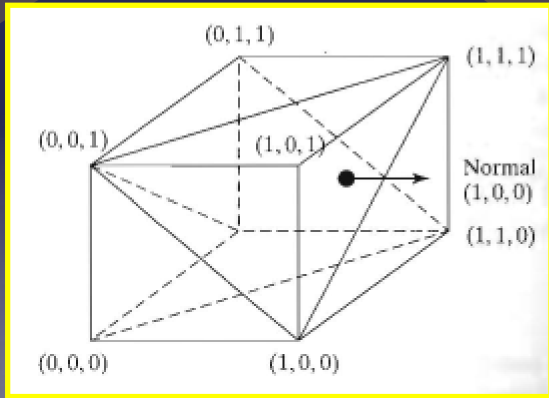


Triangular Tessellation of a unit cube

Considering only the facet with the normal vector,

solid *example_cube*
facet normal 1.0 0.0 0.0
outer loop
vertex 1.0 0.0 0.0
vertex 1.0 1.0 1.0
vertex 1.0 0.0 1.0
endloop
endfacet
… (next facet)
endsolid *example_cube*

Example of a Binary .STL file



Triangular Tessellation of a unit cube

Bytes	Data type	Description
80	ASCII	Header. No data significance.
4	unsigned long integer	Number of facets in file
4	float	i for normal
4	float	j
4	float	k
4	float	x for vertex 1
4	float	y
4	float	z
4	float	x for vertex 2
4	float	y
4	float	z
4	float	x for vertex 3
4	float	y
4	float	z
2	unsigned integer	Attribute byte count

Syntax for a Binary STL file

Syntax of a binary version of the STL file,

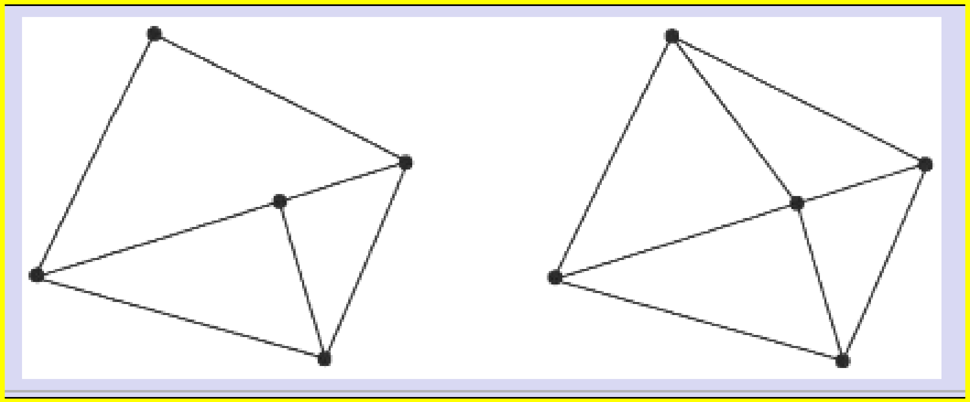
<Binary STL file>::=STL file entity name>< facet number N><facet info>
<STL file entity name>::=<80 bytes>
<facet number N>::=<4 bytes long integer>
<facet info>::=<facet normal><facet vertices><2 bytes spaces>
<facet normal>::=<1x, 1y, 1z, float, 12 bytes>
<facet vertices>::=<x1, y1, z1, x2, y2, z2, …,float, 36 bytes>

In this format, "::=" defines the term on the left-hand side with the terms on the right-hand side

←--------------------Repeat for each facet--------------------→

Example_cube	12	1.0 0.0 0.0	1.0 0.0 0.0	1.1 1.1 1.1	1.0 0.0 1.0
80 bytes	4 bytes	12 bytes	12 bytes	12 bytes	12 bytes

STL file Errors



Vertex to Vertex Rule:

Each triangle must share two vertices with each of its adjacent triangles.
i.e. the vertex of one triangle cannot lie on the side of another.

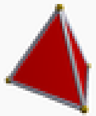
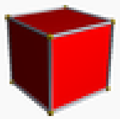
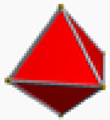
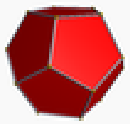
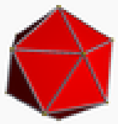
There are 3 consistency rules that you can also use to check a model:

1. The number of faces must be even.
2. The number of edges must be a multiple of three.
3. The number of edges must equal three times the number of faces.

Euler Characteristic

Euler's equation: F – E + V = 2

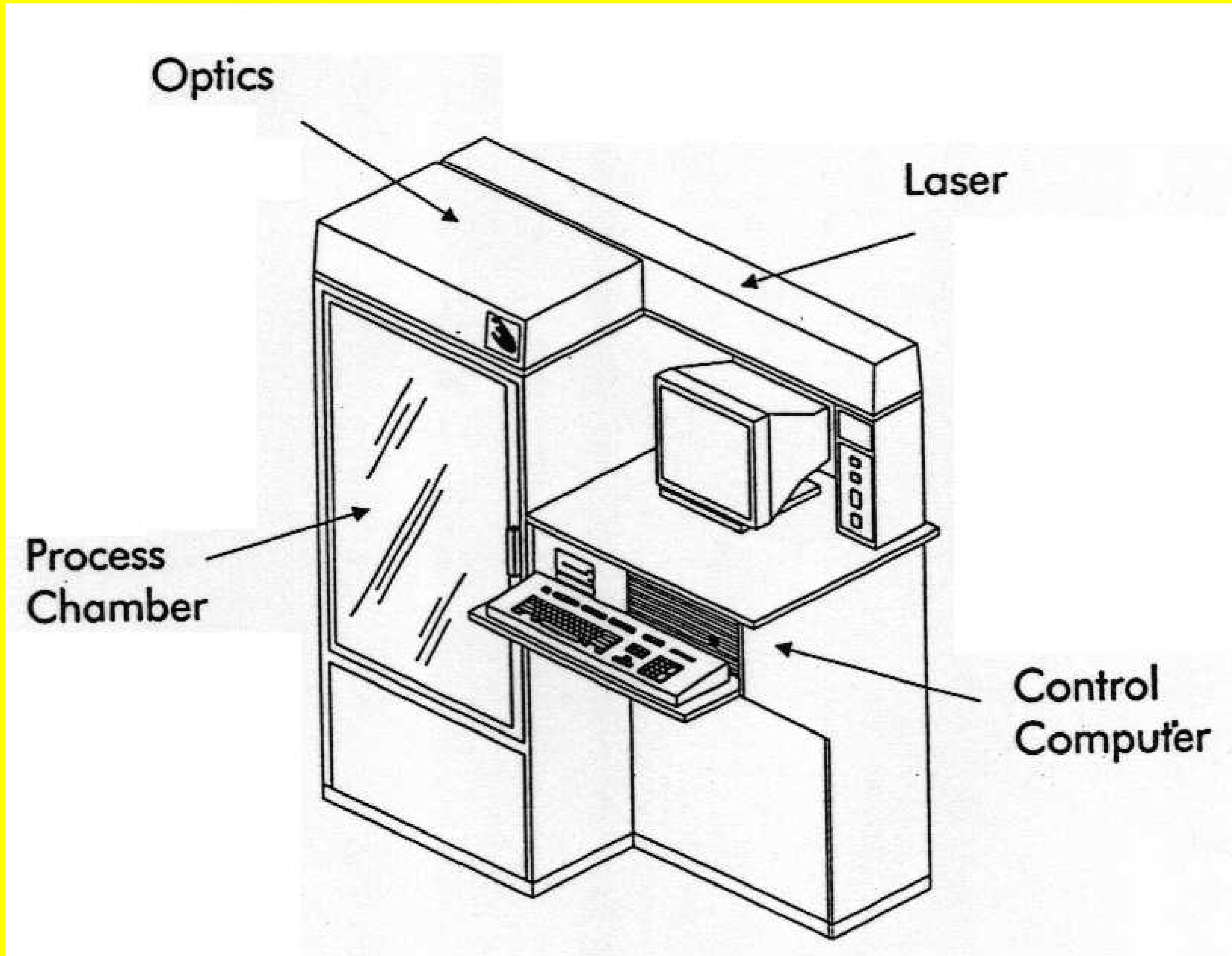
Where;
F = number of faces
E = number of edges
V = number of vertices

Name	Image	Vertices V	Edges E	Faces F	Euler characteristic: $V - E + F$
Tetrahedron		4	6	4	2
Hexahedron or cube		8	12	6	2
Octahedron		6	12	8	2
Dodecahedron		20	30	12	2
Icosahedron		12	30	20	2

Some Rapid Prototyping Techniques

- Stereolithography
- 3-D Ink-Jet Printing
- Multi Jet Modelling
- Laser Engineering Net Shaping
- Fused Deposition Modeling

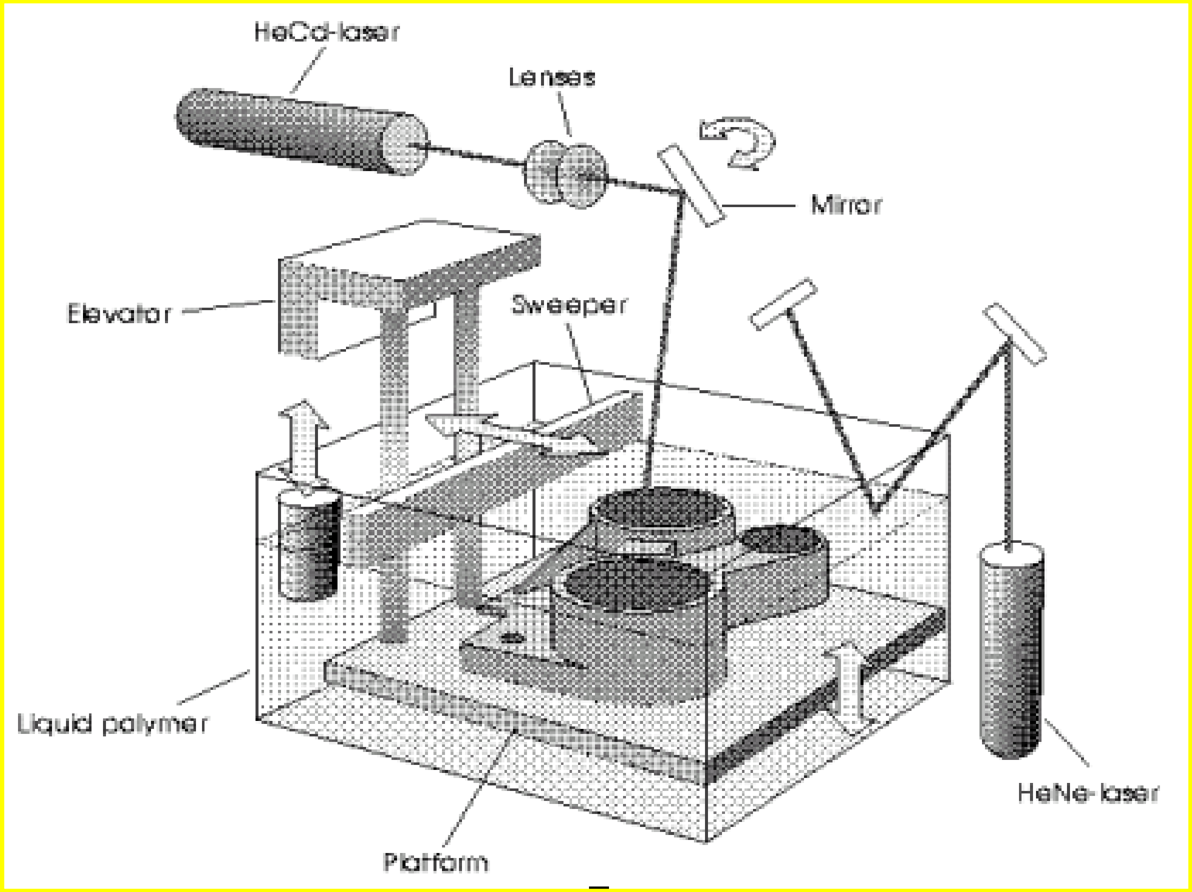
Stereolithography Apparatus Layout



Stereolithography Apparatus Layout

Stereolithography (SL)

Patented in 1986. Builds three-dimensional models from liquid photosensitive polymers that solidify when exposed to ultraviolet light

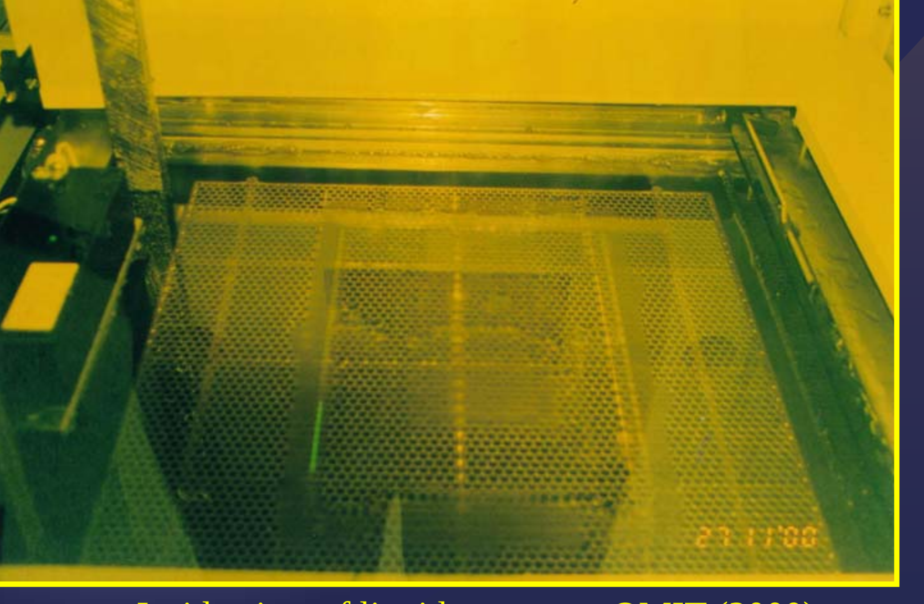


Schematic diagram of stereolithography

Stereolithography

- The model is built upon a platform situated just below the surface in a vat of liquid epoxy or acrylate resin.
- A low-power highly focused UV laser traces out the first layer, solidifying the model’s cross section while leaving excess areas liquid.
- An elevator incrementally lowers the platform into the liquid polymer.
- A sweeper re-coats the solidified layer with liquid, and the laser traces the second layer atop the first.
- Repeat process over and over.
- The solid part is removed from the vat and rinsed clean of excess liquid.

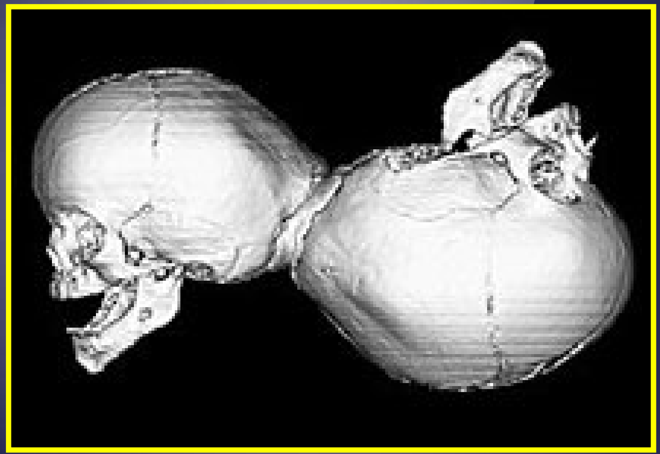
Outside view of stereolithography
Machine QMIT (2000)



Inside view of liquid epoxy vat QMIT (2000)

Typical Application

- High Resolution Medical Models



3D Rendering of CT scan showing
Siamese conjoined twins.
(Royal Brisbane Hospital Australia)

SLA BioModels of Siamese conjoined twins.
Red colouration shows the location of major
blood vessels.

Actual Implants

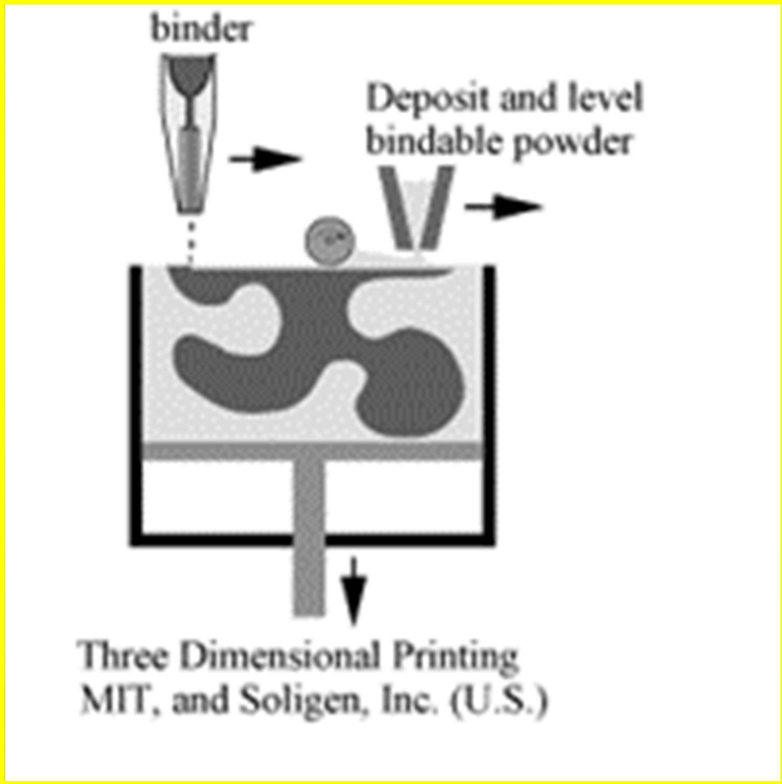
Oxford Performance Materials built a skull implant, like this one, for a US man from PEEK.
Read more: http://www.smh.com.au/technology/sci-tech/man-has-75-of-skull-replaced-by-3dprinting-20130313-2fzki.html#ixzz2SSwDI4DU
http://news.ninemsn.com.au/health/2013/05/03/00/10/vic-breakthrough-in-growing-organs

3D Z-Corp Inkjet Printer

Z-Corp Colour 3D Ink Jet Printer.

Example of investment metal
casting using 3D Ink Jet Printer.

3D Ink-Jet Process



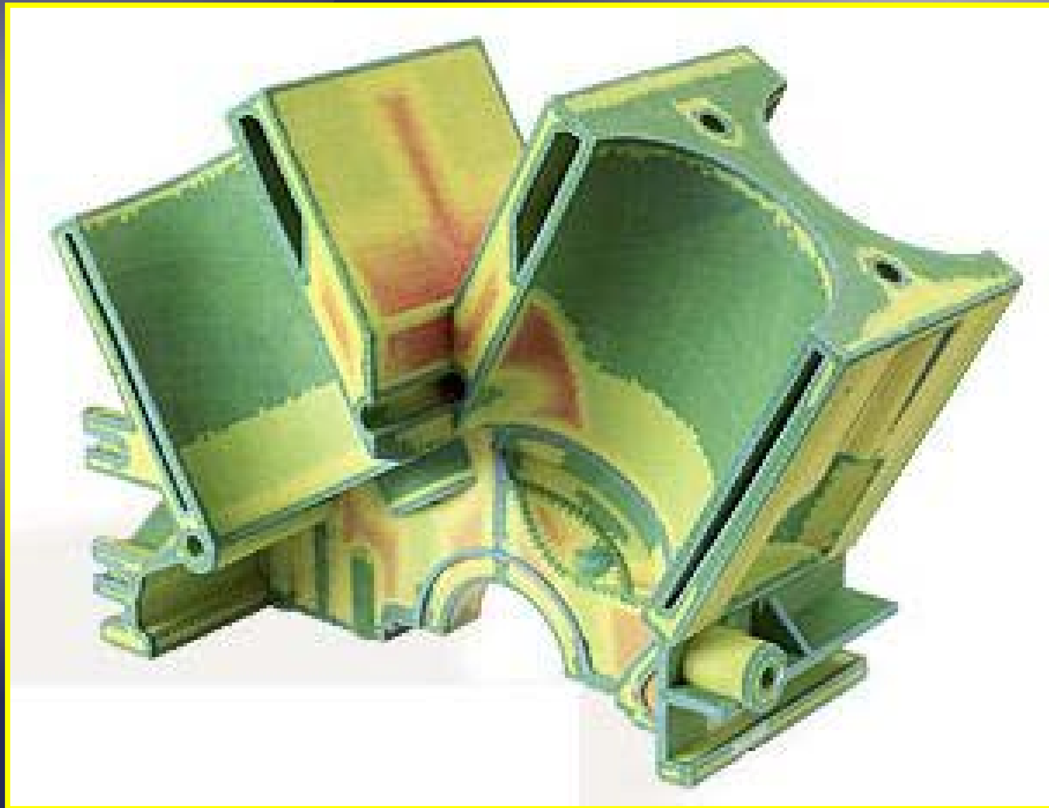
Schematic diagram of 3D Ink-Jet process.

3-D Ink-Jet Printing

- Developed at MIT
- Parts are built upon a platform situated in a bin full of powder material.
- An ink-jet printing head selectively deposits or "prints" a binder fluid to fuse the powder together in the desired areas. Unbound powder remains to support the part.
- The platform is lowered, more powder added and leveled, and the process repeated. When finished, the green part is then removed from the unbound powder, and excess unbound powder is blown off.
- Finished parts can be infiltrated with wax, CA glue, or other sealants to improve durability and surface finish.
- Typical layer thicknesses are on the order of 0.1 mm. This process is very fast, and produces parts with a slightly grainy surface.
- ZCorp uses two different materials, a starch based powder (not as strong, but can be burned out, for investment casting applications) and a ceramic powder. Machines with 4 color printing capability are available.

Typical Application

- Rapid Prototype Model of FEA Solution

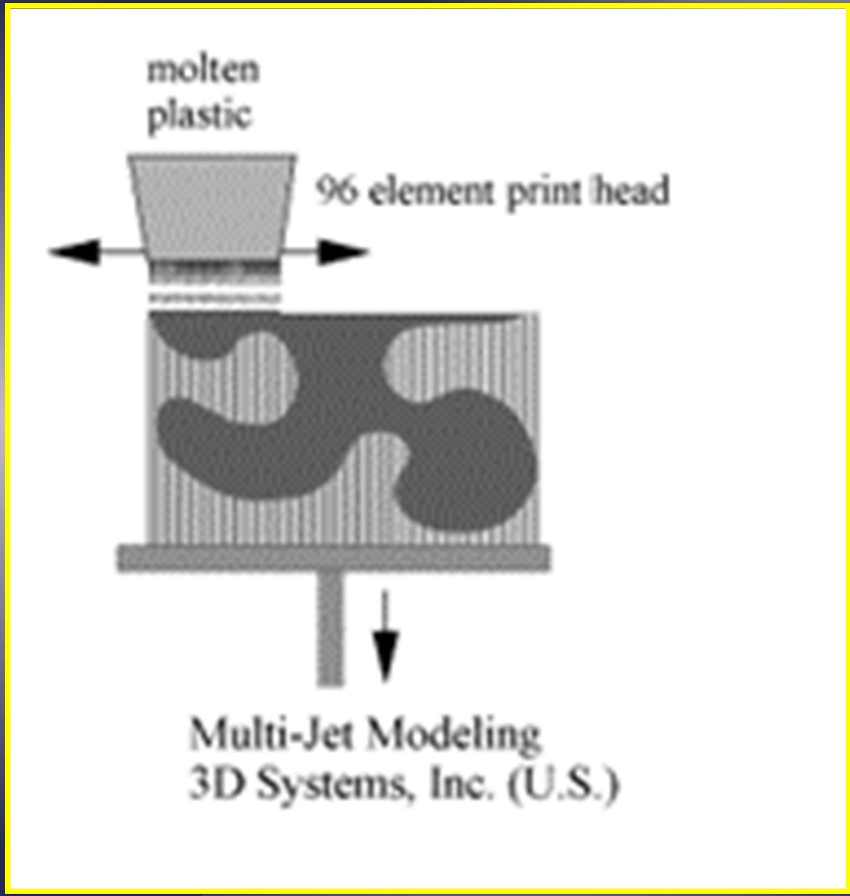


Model of manifold showing Von-Mises Stress along walls

Multi Jet Modelling (MJM)

Multi Jet Modelling Machine.

Multi Jet Modelling (MJM) Process



Schematic Diagram of Multi Jet process.

Multi Jet Modelling

- 3D Systems version of the ink-jet based system is called the Thermo-Jet or Multi-Jet Printer.
- It uses a linear array of print heads to rapidly produce thermoplastic models.
- If the part is narrow enough, the print head can deposit an entire layer in one pass, otherwise, the head makes several passes.

Typical Application

- Investment Casting - Automotive

Multi Jet Modelling Component of Automotive component

(LENS) Laser Engineering Net Shaping

- Deposits metals in an additive process
- Produces parts with material equal to or better than wrought materials
- Parts built from the inside out
- Depth to Dia ratio of up to 70:1 vs 10:1 for machining

Process Basics

Developed at Sandia National Laboratories

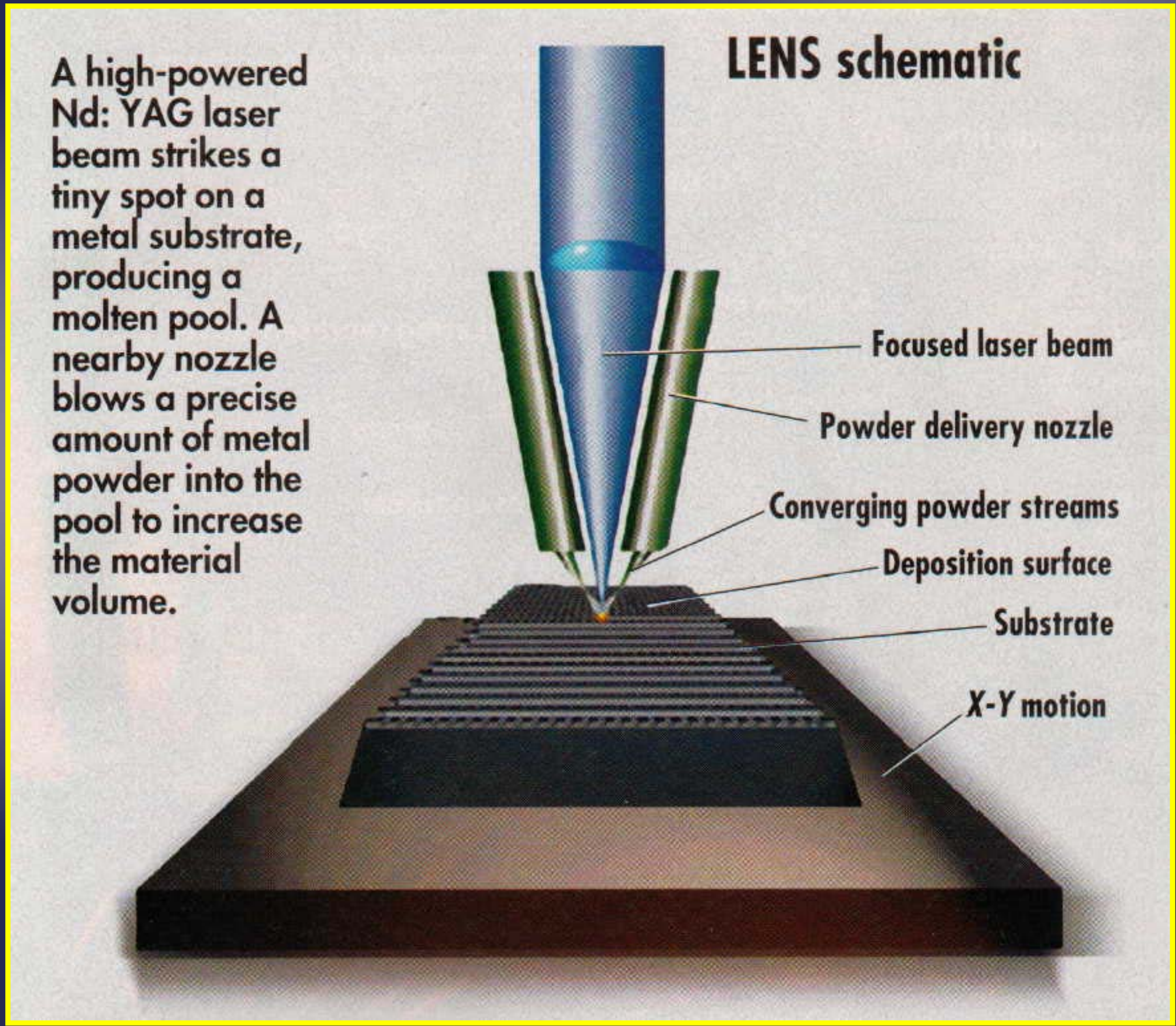
1. High-powered Nd:Yag laser beam strikes a small spot on metal substrate, producing a molten pool

2. A nozzle blows a precise amount of metal powder into the pool to increase the material volume.

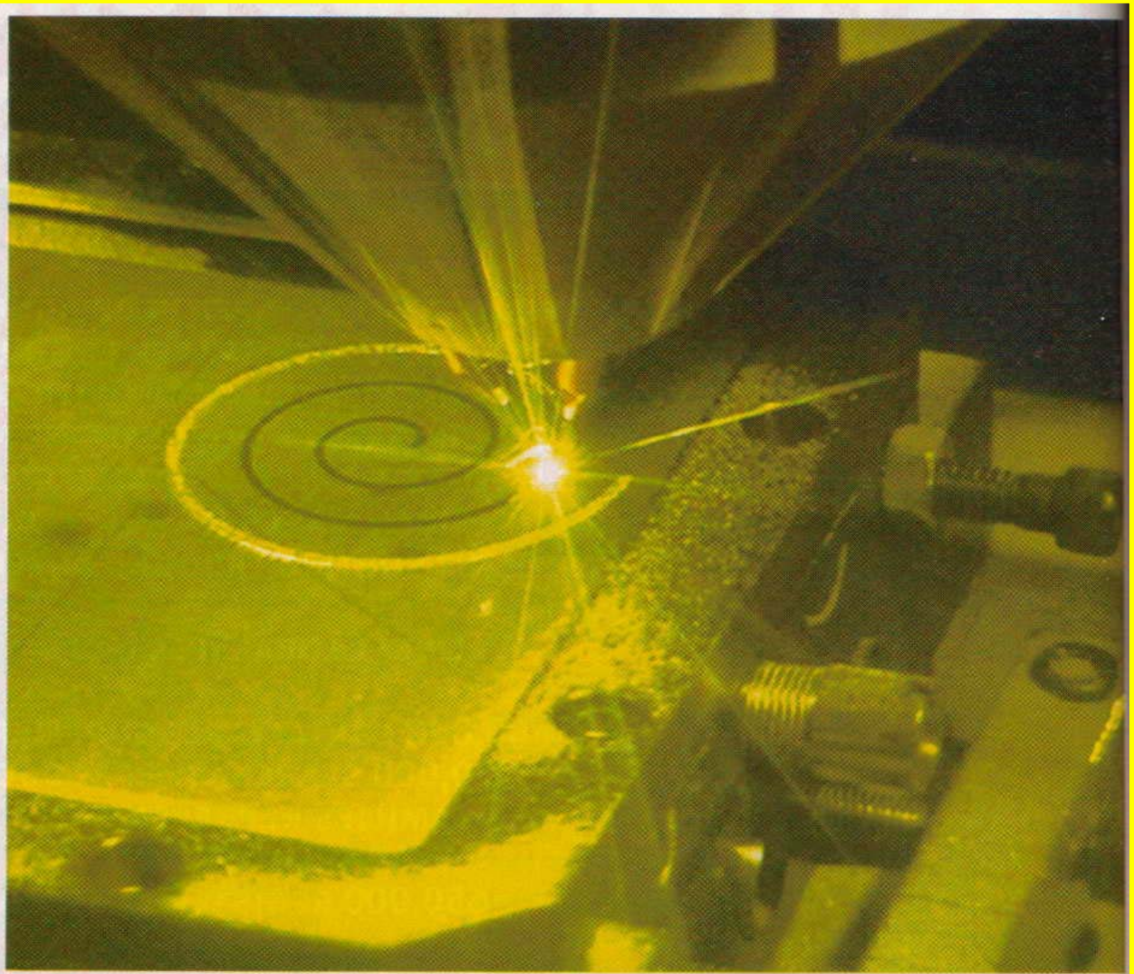
3. Powder-deposition process completes layer and moves up in the Z direction.

4. Builds layer upon layer …

LENS Schematic



LENS

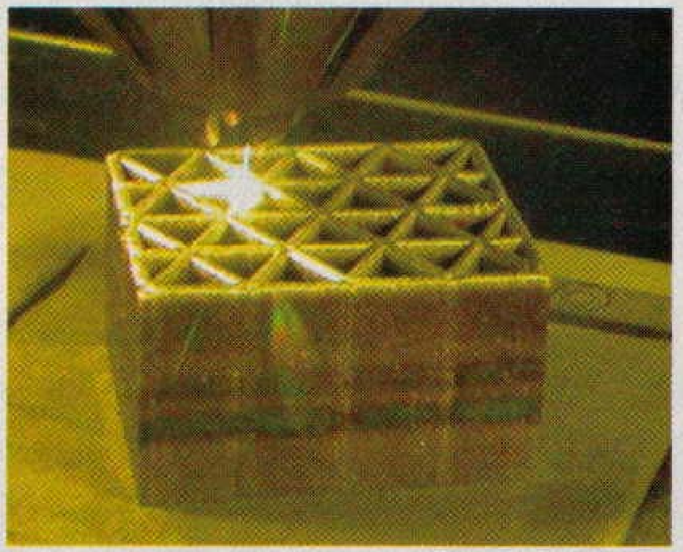


LENS additive manufacturing systems dispense metal powders in patterns dictated by three-dimensional CAD models.

LENS

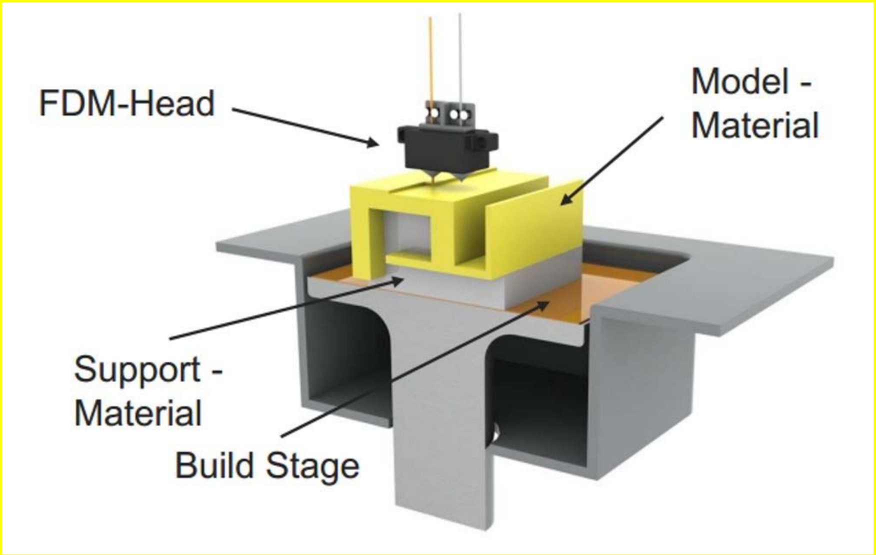
MATERIAL PROPERTIES

Material type	Ultimate tensile strength (kpsi)	Yield strength (kpsi)	Elongation (% in 1 in.)
LENS 316 stainless steel	115	72	50
316 stainless steel wrought stock	85	35	50
LENS Inconel 625	135	84	38
Inconel 625 wrought stock	121	58	30
LENS Ti-6Al-4V	170	155	11
Ti-6Al-4V wrought stock	130	120	10

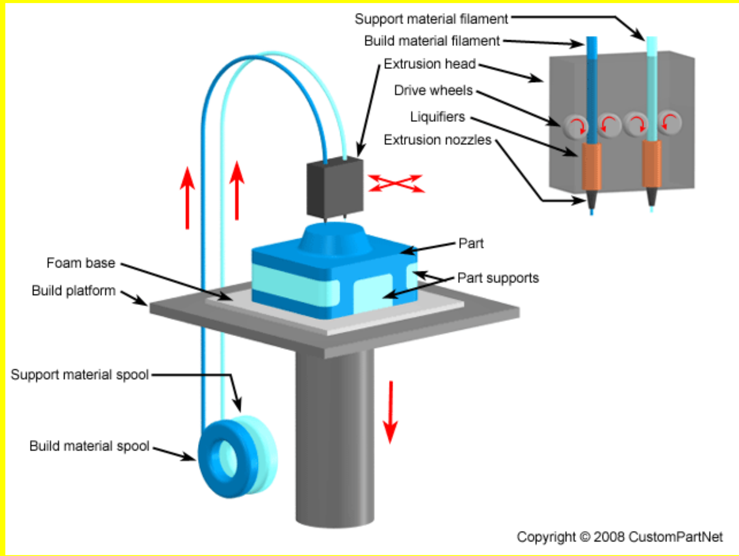


The LENS process easily produces parts with unusual or complex internal geometries, such as the honeycomb interior of the part pictured here.

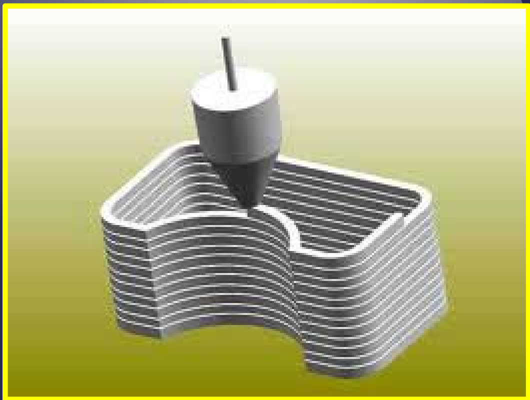
Fused Deposition Modelling



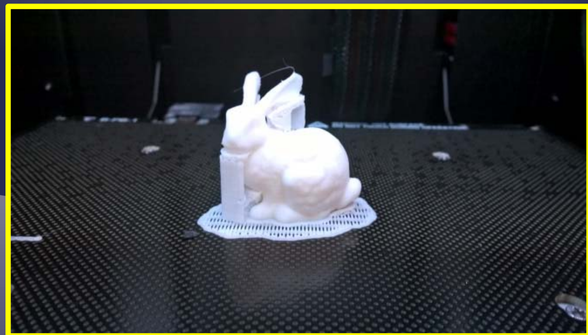
https://www.sculpteo.com/



http://3devo.eu/guide-fdm-printable-plastics-3d-printing-filament/



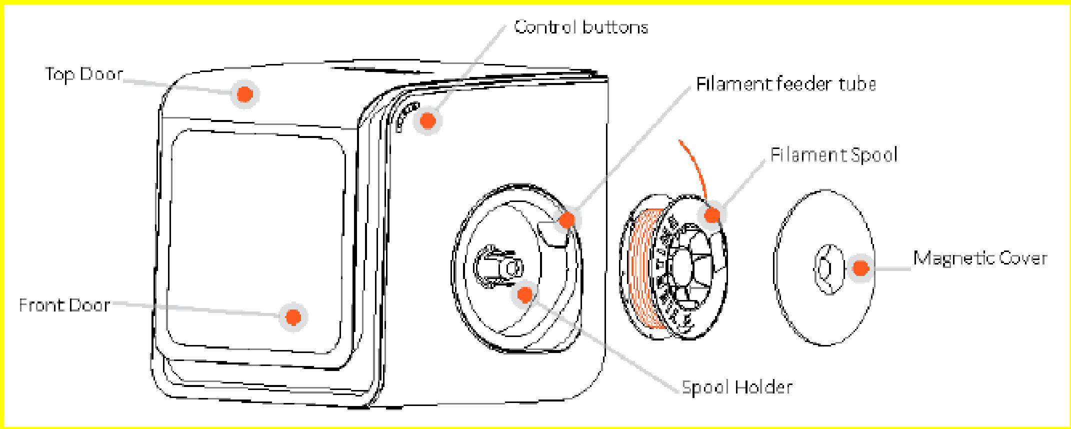
http://3dware.ir/en/references/articles/162-everything-about-fdm-technology

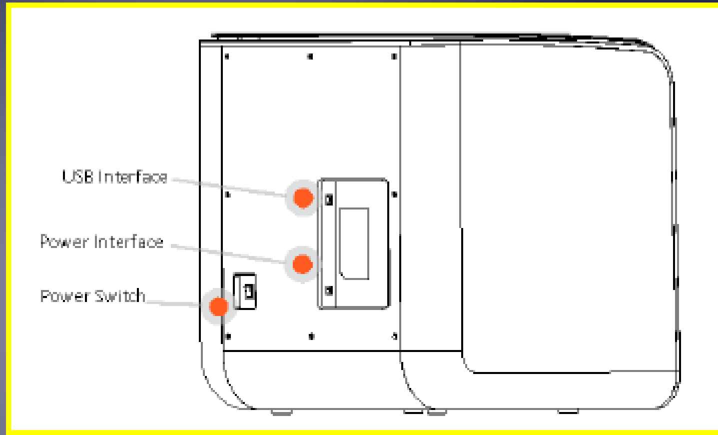


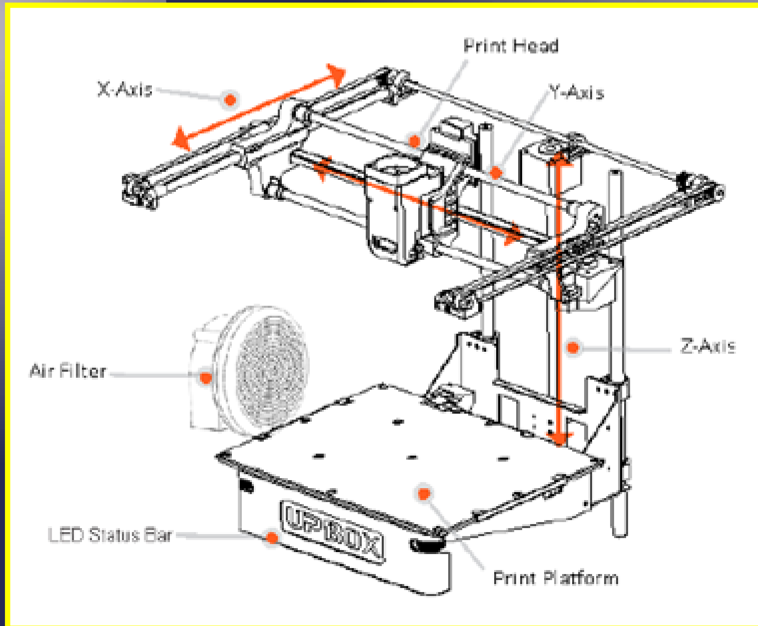
http://3dprinterplans.info/up-box-review/

UP BOX – FDM at its Best!

UP BOX – Breakdown

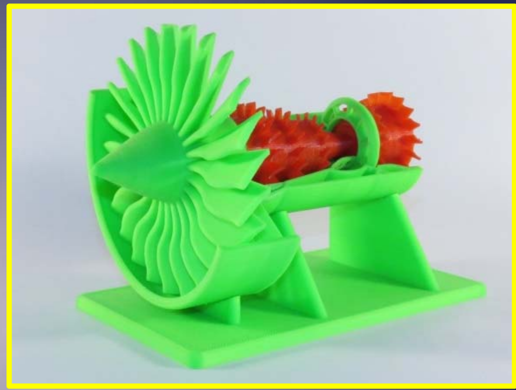






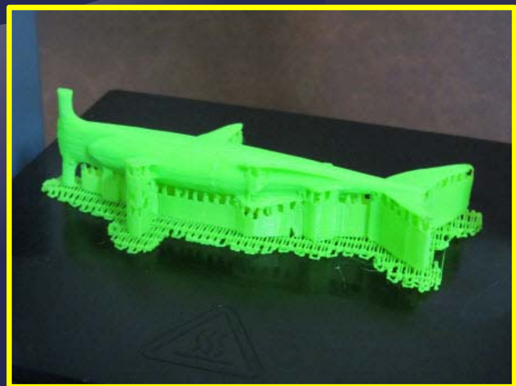
Common Acronyms

ABS Acrylonitrile Butadiene Styrene: Lightweight thermoplastic with resistance to high heat and is the most common plastic used in 3d printing. A strong and easy material to print with, but printing large parts can warp.

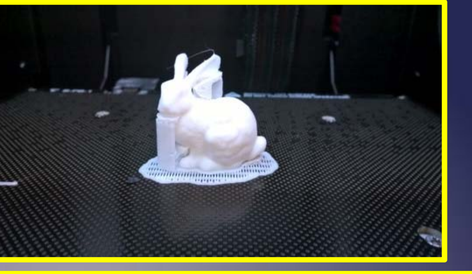


PLA Polylactic Acid: A biodegradable material derived from corn. Unlike ABS it warps less but support removal can be harder. A great material to obtain low cost steel parts by sending the PLA printed part to a foundry to use investment casting / lost wax casting.

Raft: The printer lays down a foundation before it starts print the model. The raft is used to anchor the model down onto and into the perfboard. During the printing of the raft, any unevenness in the leveling of the platform is correct during the raft.

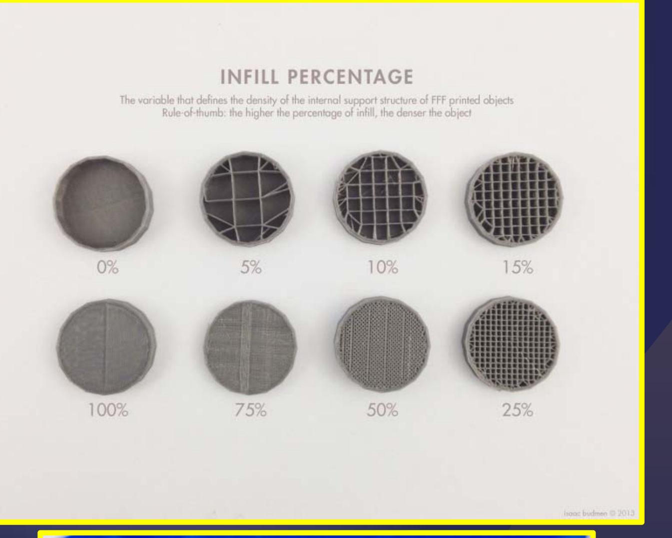


Common Acronyms



Perfboard: A reusable and removal build platform that the model is printed onto.

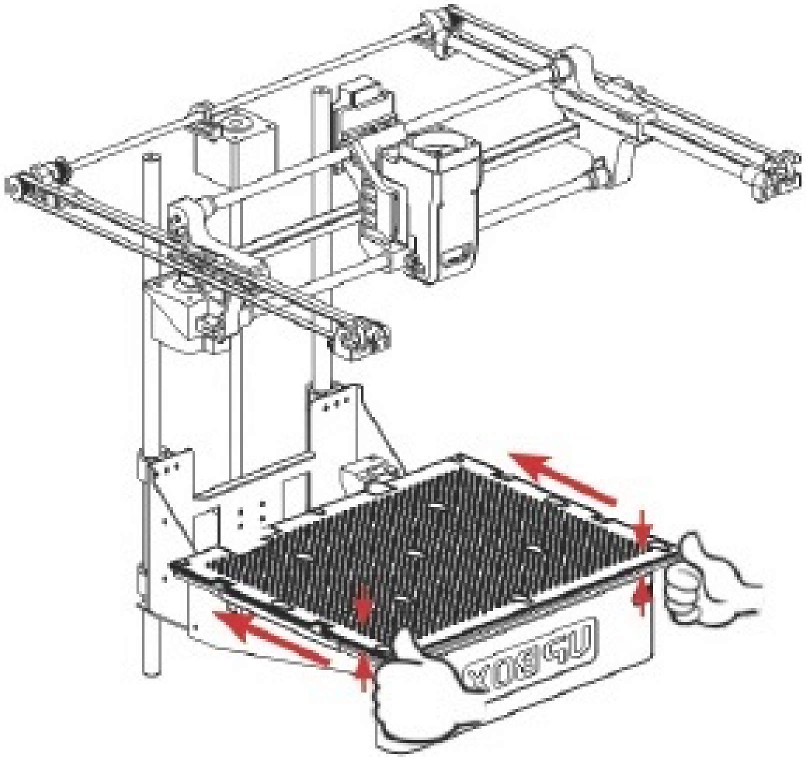
Shell: The external layers of the printed part, much like an egg shell.



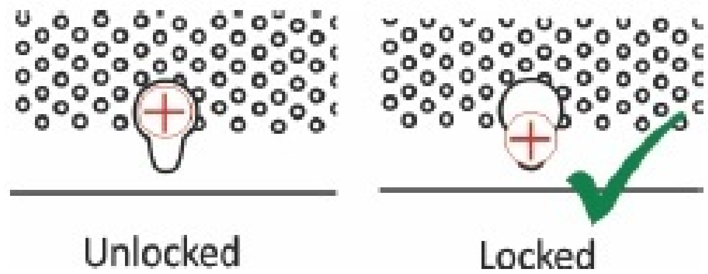
Infill: The internal honeycomb structure that gives the part strength.

Warping: When a part lifts away from the platform. Caused by the uneven cooling of the part during printing as the material shrinks back to its normal state. All materials expand when heated and shrink when cooled. Molten plastic as it is printed is in an expanded state, as the part cools it contracts. The larger the part the worse the effect and ABS is more prone to warping where PLA does not warp as much.

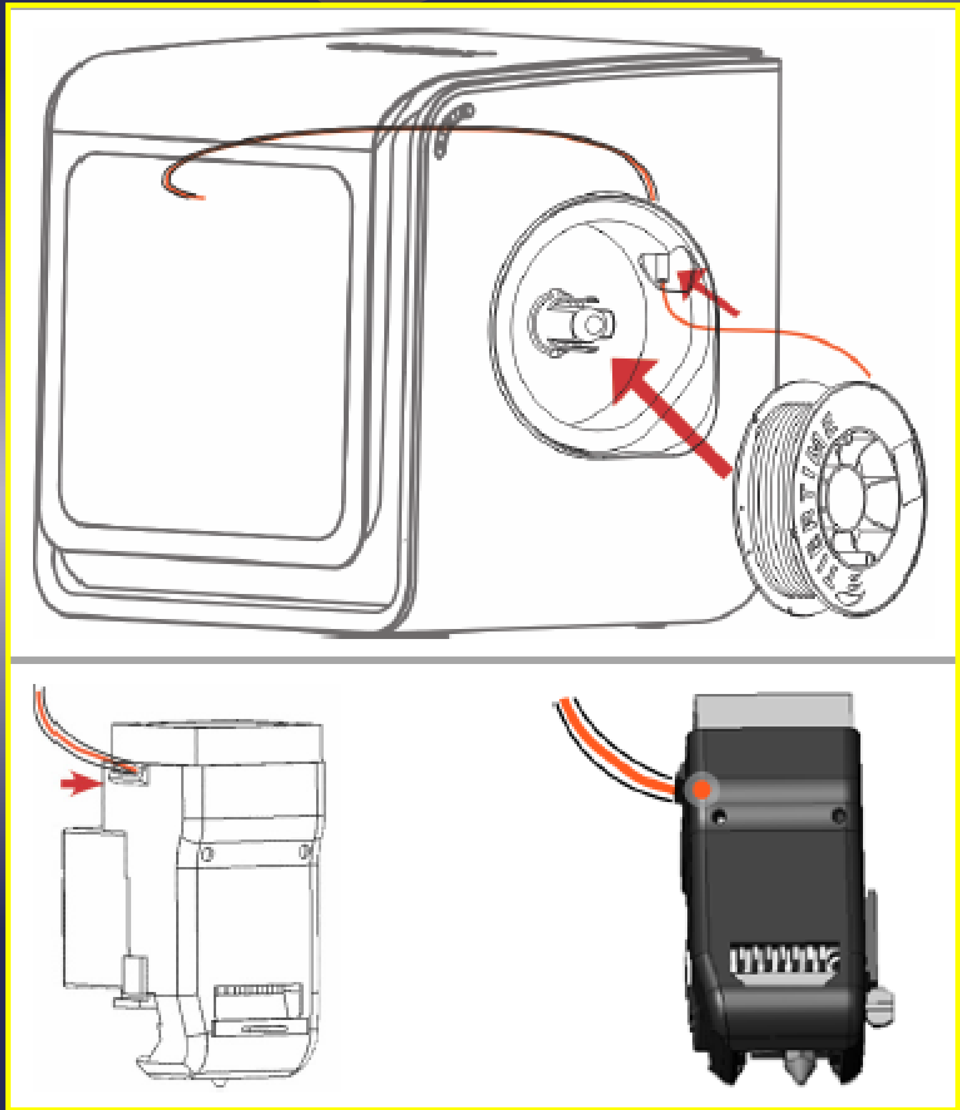
UP BOX – Installing Perfboard



Place the Perfboard onto the build plate and lock it into place with the locating holes, so the perfboard is completely flat against the metal plate.

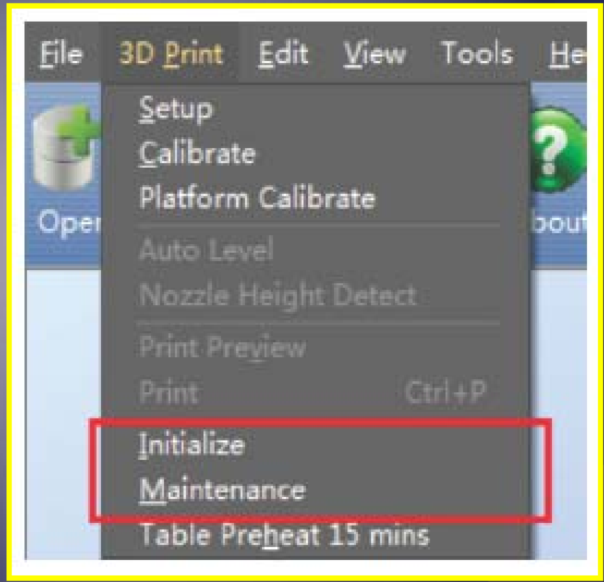


UP BOX – Installing Filament



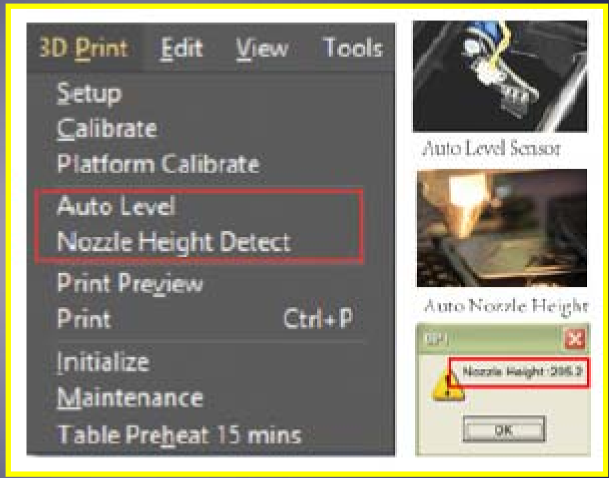
UP Software - Initialization

- Initialization sends the printer to find its home position on its X,Y and Z axis.
- Initialization is required every time the printer is switched on.



UP Software – Automatic Calibration

- By far the most important part of 3D printing is having a level platform. On the UP Box this is achieved automatically by using the Auto Level option. The Auto Level option should be used on the initial print or if Print problems develop.

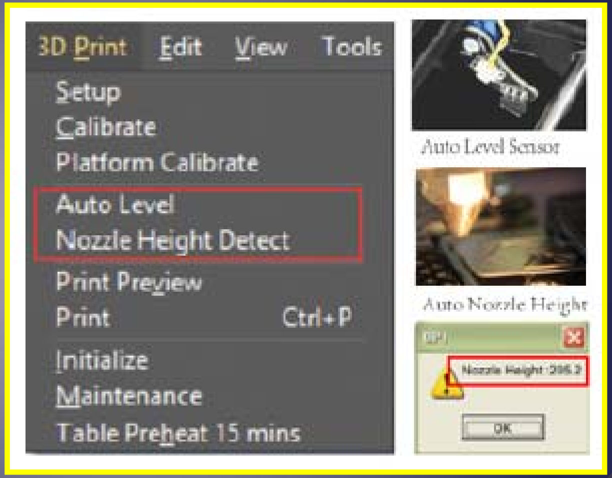


- Auto level samples the height of nine equispaced points on the area of the fixed perf board.

- Once Auto level completes, the nozzle height is automatically set.

UP Software – Extrusion

- By far the most important part of 3D printing is having a level platform. On the UP Box this is achieved automatically by using the Auto Level option. The Auto Level option should be used on the initial print or if Print problems develop.



- Auto level samples the height of nine equispaced points on the area of the fixed perf board.

- Once Auto level completes, the nozzle height is automatically set.

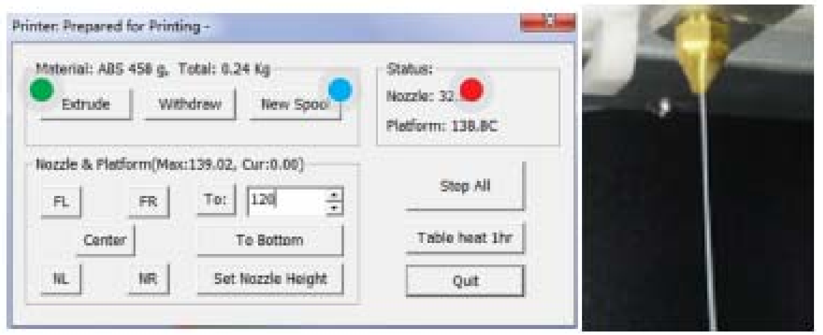
UP Software – Test Extrusion

- If this is a new spool, Select New Spool > Select ABS as your material and then O.K.

- Select Extrude and should hear "beep".

- Once the Nozzle temperature reaches 260º you should hear a beep.

- Push the filament into the nozzle and wait to see material coming out of the nozzle.

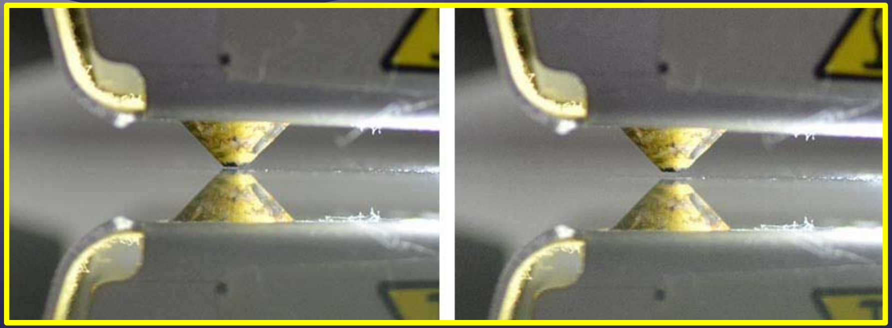


Nozzle Height Check

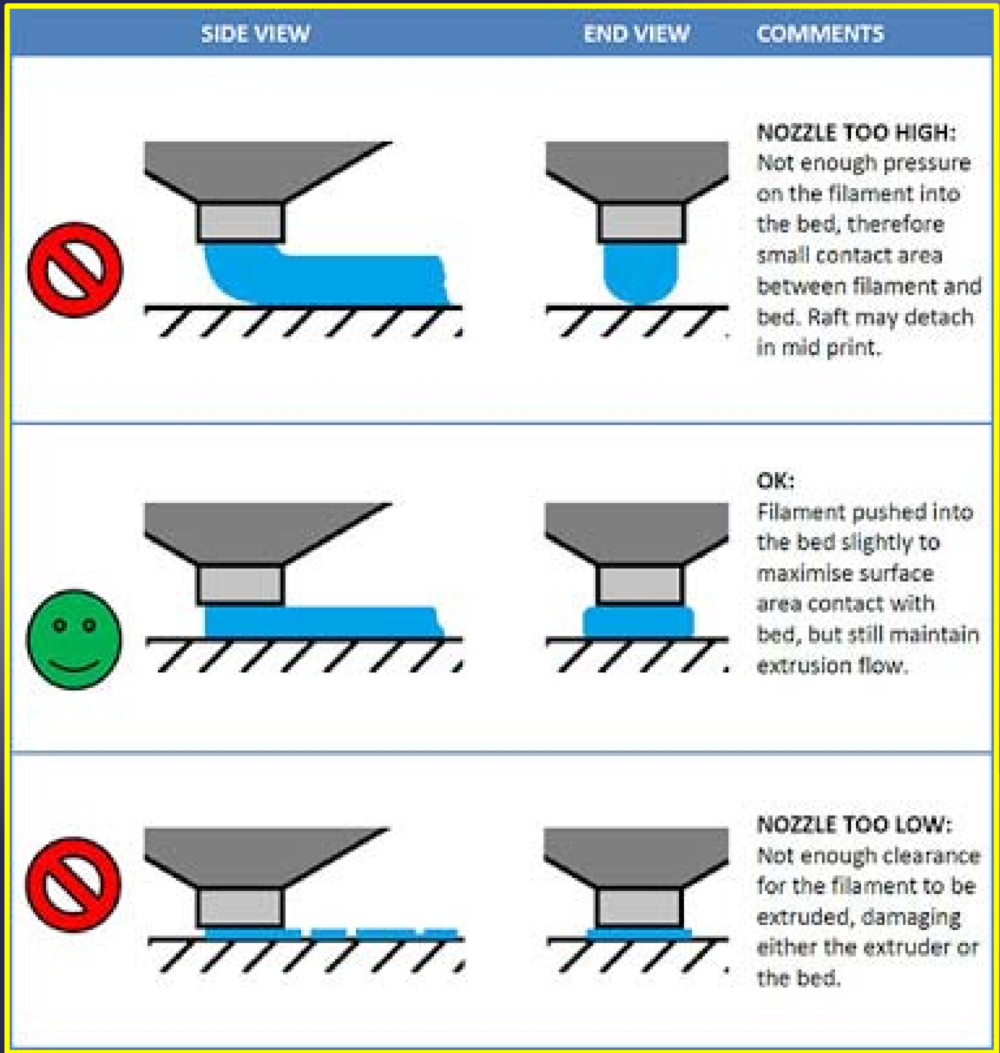
- Good nozzle height can be observed if the first layer is “squished” flat on to the perforated board.

- If the nozzle is too far away from the perforated board, the user can observe deposition that is very thin and “squiggly”.

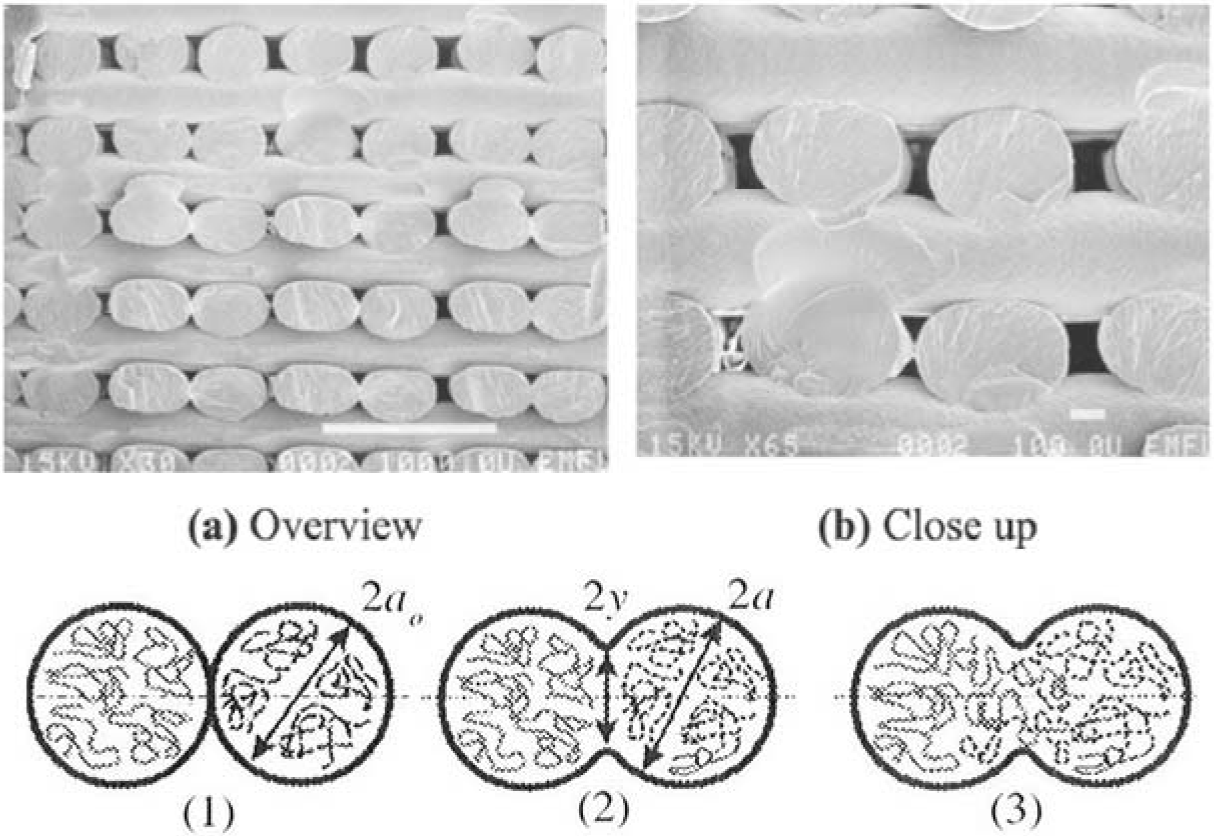
- If the nozzle is too close to the perforated board, the user will hear an audible “clicking”.



Overview of Nozzle Height



Mesostructure – Polymer Bonding

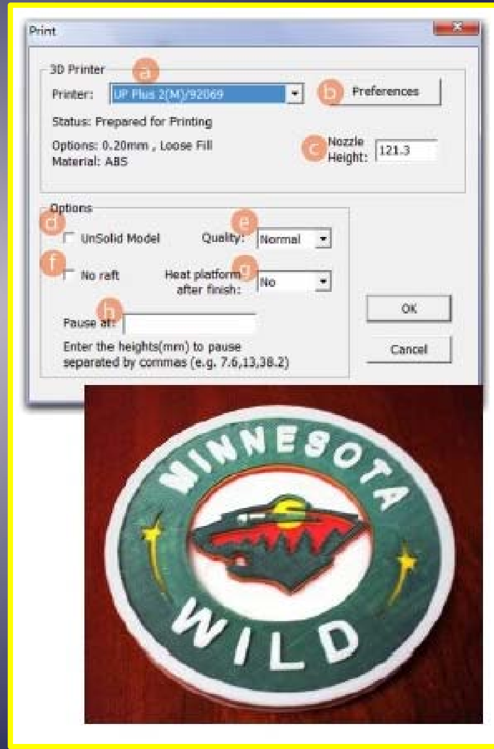


(a) Overview (b) Close up

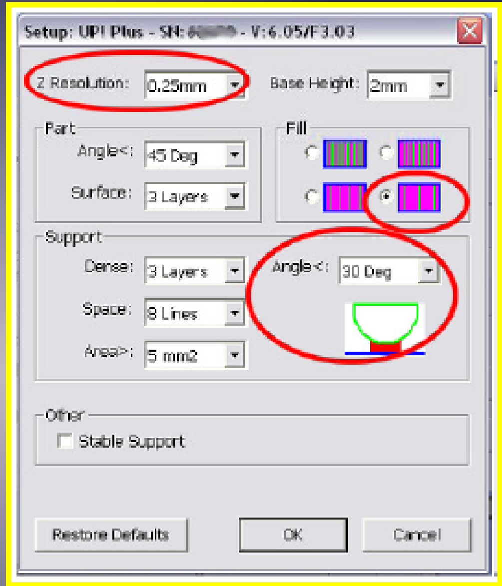
(1) Wetting/Contact (2)Diffusion/Neck growth (3)Randomisation

Printing

a. Printer: Choose from connected UP printers.
b. Preferences: Covered in next slide.
c. Nozzle height: Platform height fine tuning.
d. UnSolid Model: Advanced Feature
e. Quality: Relates to print speed.
   Slower = Better quality.
   Turbo = Super fast & Draft quality.
f. No raft: Prints without a raft.
g. Post Heating: How long to heat after completion.
h. Used when changing colours during a print. The image on the right was made raising the height of each coloured element of the logo. e.g. 2.4,3.1,3.6 - Start with white, printer passes at 2.4mm, withdraw white and add red, resume printing, printer passes at 3.1 and so on...



Print Preferences

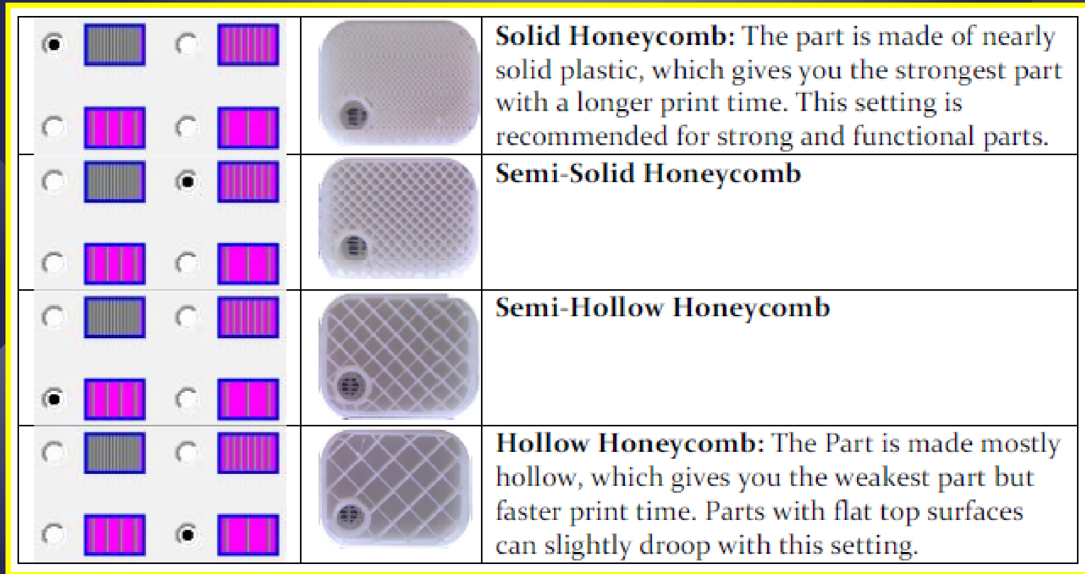


Z Resolution:

Sets the print resolution (layer thickness) of the printer. This can be between 0.2mm per layer to 0.4mm per layer. The finer the layer thickness, the better quality, the stronger the printed part and the longer it takes to print.

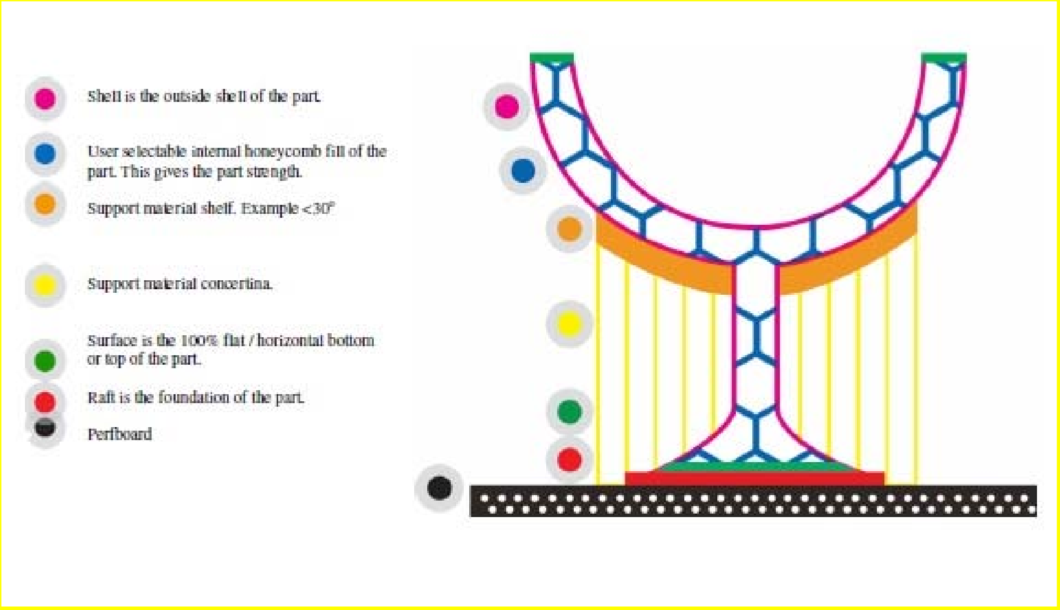
Fill:

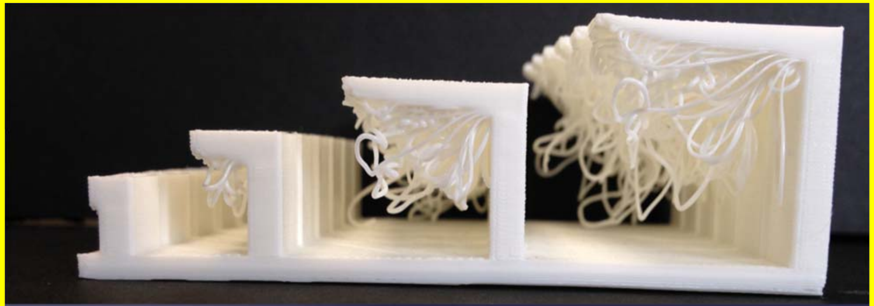
There are four types of honeycomb fill that the interior of parts are made of. These cut away images below show the four different internal fill types.



Solid Honeycomb: The part is made of nearly solid plastic, which gives you the strongest part with a longer print time. This setting is recommended for strong and functional parts.	
Semi-Solid Honeycomb	
Semi-Hollow Honeycomb	
Hollow Honeycomb: The Part is made mostly hollow, which gives you the weakest part but faster print time. Parts with flat top surfaces can slightly droop with this setting.	

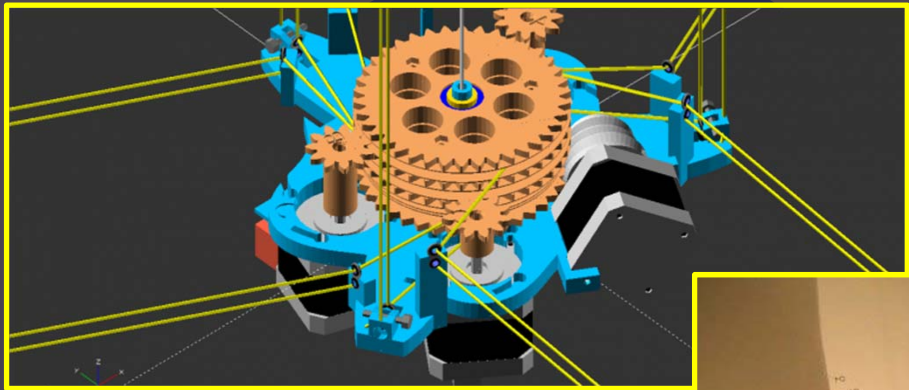
Overhang

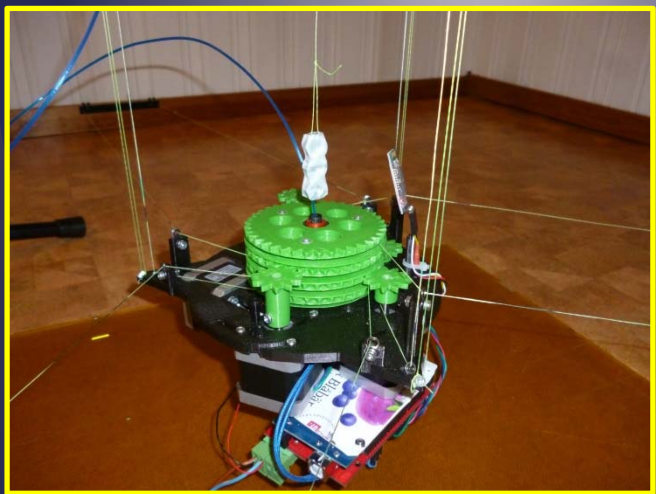


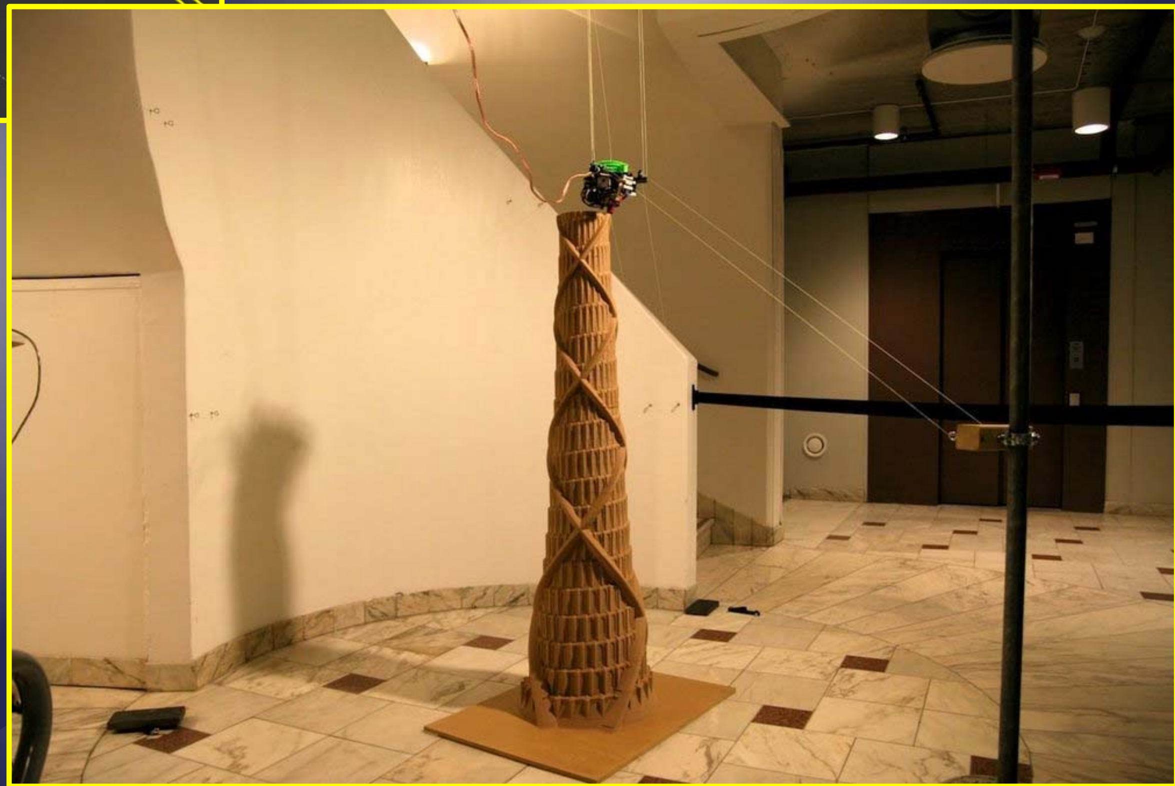


Failed Horizontal Overhangs

Extreme FDM – The Hangprinter







https://www.youtube.com/watch?v=Jk4fhQvNoaM

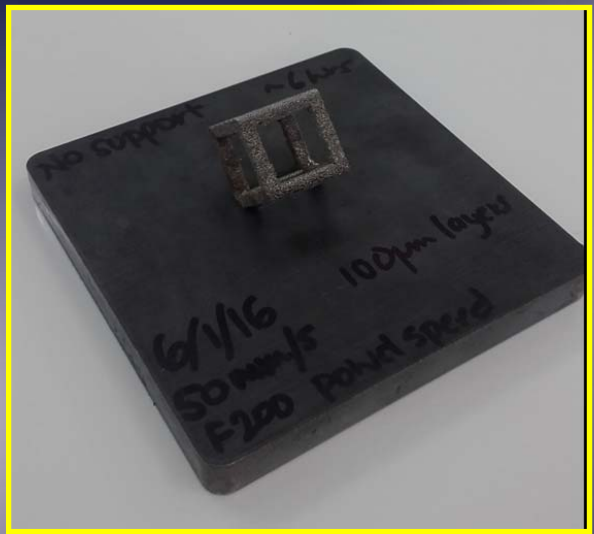
Fixtures for Additive Manufacturing (AM)

Removal of Component from AM Process - FDM

Removal of Component from AM Process SLA or SL (Pre Oven)

Removal of Component from AM Process – SLS

Fixtures for Additive Manufacturing (AM)



Fixture Method of Various Components from Metal AM Process - Direct Energy Deposition (DED)

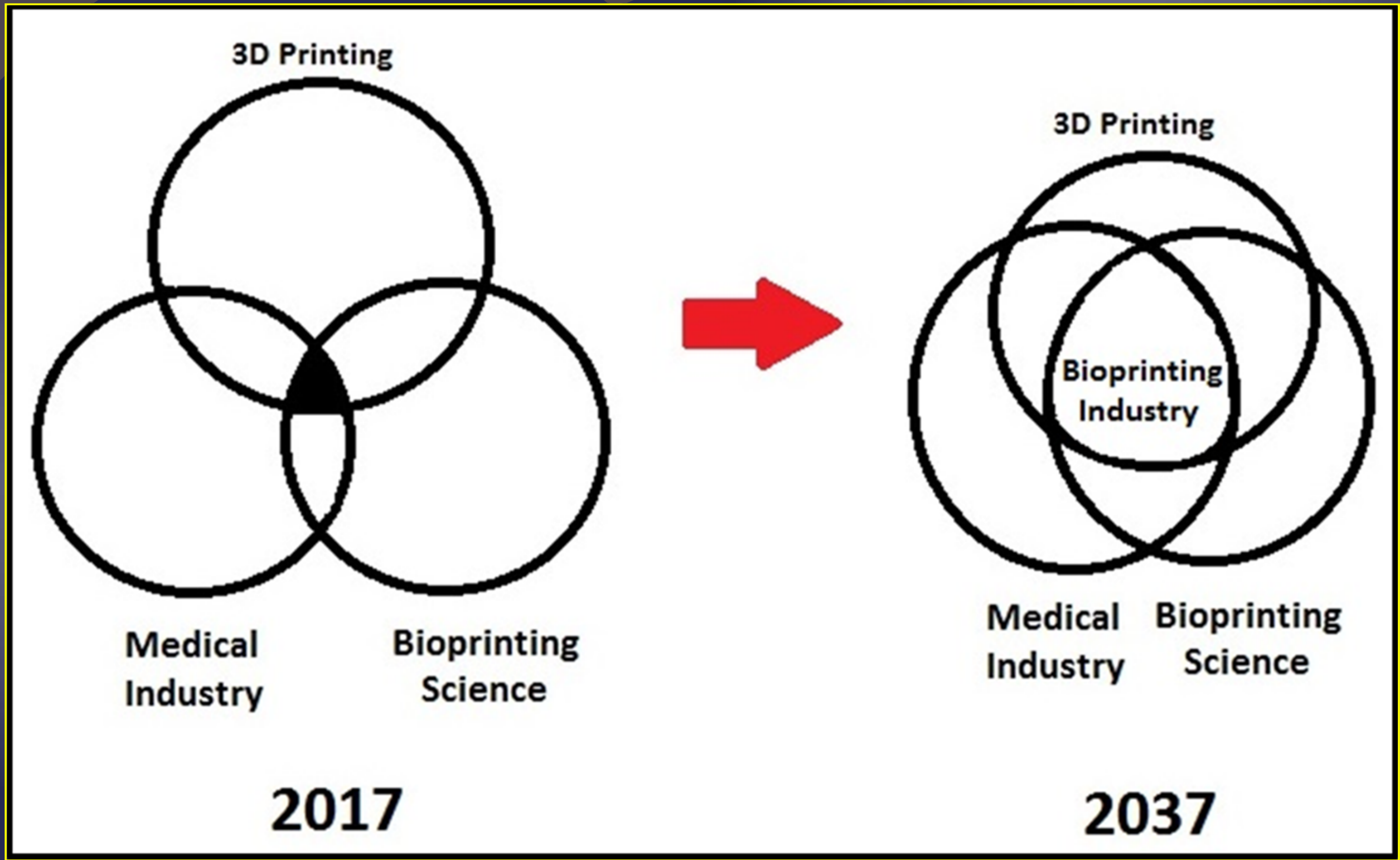
Machine is also Capable of;

Selective Laser Melting (SLM)

Selective Laser Sintering (SLS)

Aurora Labs (Perth)

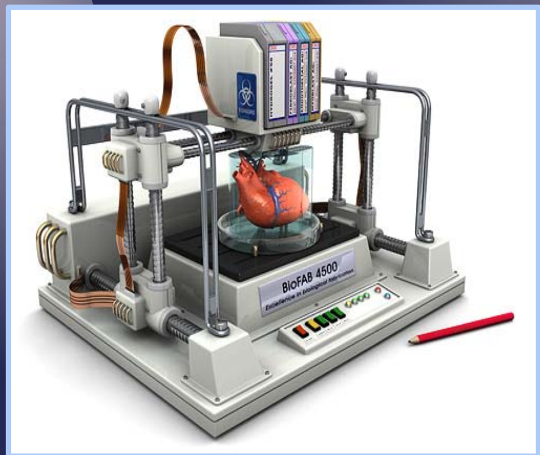
Additive Manufacturing (AM) – Speculative Future



Working Theory Framework Bioprinting
Jureidini-Briozzo, V 2017 Additive Manufacturing Bioprinting

https://www.youtube.com/watch?v=g2ZTWHsO8l0

Additive Manufacturing (AM) – Speculative Working Theory Framework Bioprinting



Barnatt, C 2014, 3D PRINTING, Barnatt, LexingtonQa

References

Additive Manufacturing Technologies (Gibson, Rosen, Stucker)
If you ever only one book on RP, buy this one. Springer is the publisher.

3D Printing and Additive Manufacturing (Chua, Leong)
If you interested in the mathematics of STL files, this is the best. The images could be improved and some points raised will date.

3D Printing (2nd Ed now into 3rd) (Barnatt)
If you are interested in possible future directions of RP rather than details, its an easy and brillant read.

Fabricated The New World of 3D Printing (Lipson Kurman)
An easy book, great images by Lipson who is a pioneer in the area of RP tinkering.